



## Assessing Microneurosurgical Skill with Medico-Engineering Technology

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■ **OBJECTIVES:** Most methods currently used to assess surgical skill are rather subjective or not adequate for microneurosurgery. Objective and quantitative microneurosurgical skill assessment systems that are capable of accurate measurements are necessary for the further development of microneurosurgery.

■ **METHODS:** Infrared optical motion tracking markers, an inertial measurement unit, and strain gauges were mounted on tweezers to measure many parameters related to instrument manipulation. We then recorded the activity of 23 neurosurgeons. The task completion time, tool path, and needle-gripping force were evaluated for three stitches made in an anastomosis of 0.7-mm artificial blood vessels. Videos of the activity were evaluated by three blinded expert surgeons.

■ **RESULTS:** Surgeons who had recently done many bypass procedures demonstrated better skills. These skilled surgeons performed the anastomosis with in a shorter time, with a shorter tool path, and with a lesser force when extracting the needle.

■ **CONCLUSIONS:** These results show the potential contribution of the system to microsurgical skill assessment. Quantitative and detailed analysis of surgical tasks helps surgeons better understand the key features of the required skills.

### INTRODUCTION

Skills are a very important component of surgery and training. Conventionally, a surgeon's skills have been assessed through visual observation combined with clinical

outcomes. To improve the assessment of skills and facilitate training, however, an objective method of measurement is needed.

To date, many surgical skill–assessment methods and systems have been developed (10, 12) and include methods designed to assess microsurgery skills (5). Most of these methods, however, are video-based and rather subjective. Other objective and quantitative assessment methods use devices and simulators, but most of these were designed for laparoscopy; thus, they mainly evaluate psychomotor performance and economy of motion (8). The accuracy of manipulation, however, is the most important skill in microsurgery. Therefore, we need objective and quantitative systems that can accurately measure this aspect to assess microsurgical skill.

This work describes a new microsurgical skill assessment system for neurosurgery with motion-measuring and force-sensing capabilities, without using specific simulator products. The system incorporates infrared optical motion tracking markers, an inertial measurement unit (IMU), and strain gauges mounted on tweezers to record instrument manipulation. Herein, the details of the system and the experiments conducted to assess neurosurgical skill are described, and the findings are compared with conventional and subjective video assessment of the procedures.

### MATERIALS AND METHODS

#### Microsurgery Skill-Assessment System

The skill-assessment system shown in Figure 1, which has been described previously with preliminary results (3), was designed to be mobile. This mobility facilitates carrying out skill-assessment experiments at conferences to recruit surgeons with a wide range of clinical experience. Although this type of on-site measurement can be influenced by a surgeon's physical

#### Key words

- Anastomosis
- Medical engineering
- Microsurgery
- Neurosurgery
- Surgical skill assessment
- Training

#### Abbreviations and Acronyms

IMU: Inertial measurement unit

VAS: Visual assessment score

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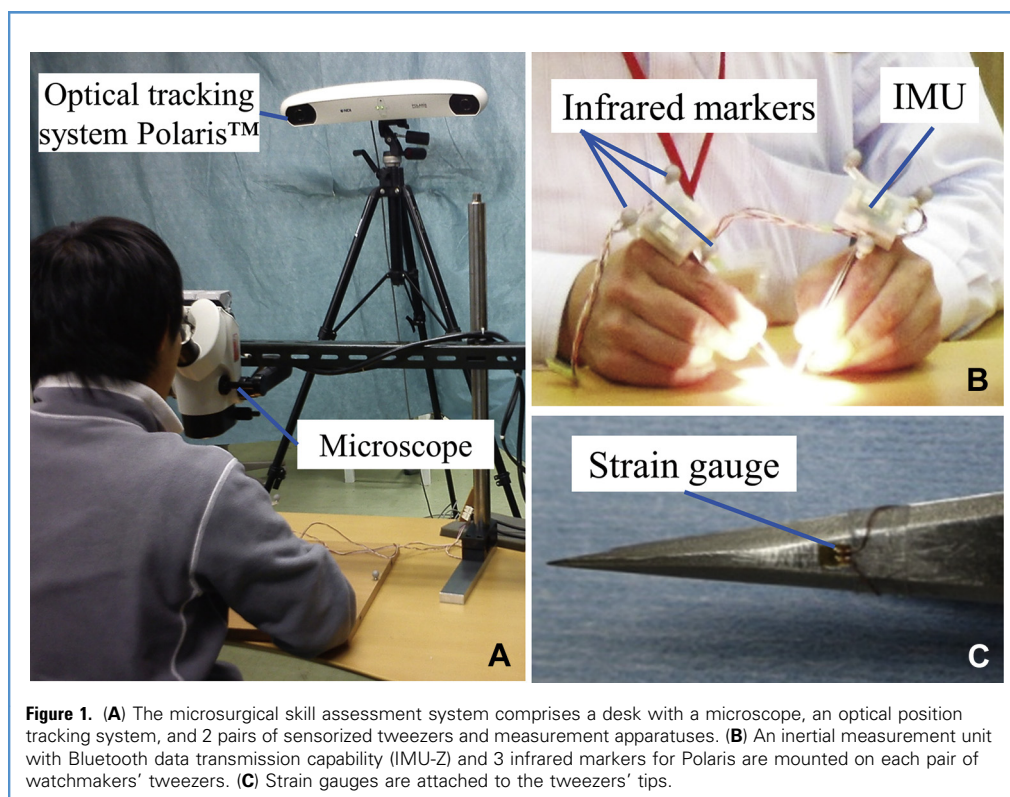
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**Figure 1.** (A) The microsurgical skill assessment system comprises a desk with a microscope, an optical position tracking system, and 2 pairs of sensorized tweezers and measurement apparatuses. (B) An inertial measurement unit with Bluetooth data transmission capability (IMU-Z) and 3 infrared markers for Polaris are mounted on each pair of watchmakers' tweezers. (C) Strain gauges are attached to the tweezers' tips.

condition, motivation, and feelings of tension, we assumed that the differences in ability between unskilled and skilled surgeons would still be evident.

The system comprises a desk with a microscope, 2 pairs of sensorized tweezers, and measurement apparatuses. An IMU unit with Bluetooth data transmission capability (IMU-Z, ZMP Inc., Tokyo, Japan) and 3 infrared markers for the optical position tracking system (Polaris Spectra, Northern Digital, Inc., Waterloo, Ontario, Canada) were mounted on each pair of watchmaker's tweezers (K-1AA, KFI, Japan). Strain gauges (KFR-02N-120-C1-11 N10C2; Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan) also were attached to measure the needle-gripping force, with a maximum error of 1% up to a force of 5 N. The total weight of the sensorized tweezers was 38 g. The sampling frequency of optical motion tracking was 60 Hz, and the theoretical root mean square error was 0.30 mm. The sampling frequency of the IMU unit was 100 Hz, and the theoretical resolution was 0.0096 m/s<sup>2</sup> for acceleration and 0.24 degrees per second for angular velocity. Data from the IMU sensor were not used for the analysis presented in this work.

### Experimental Methods

A registration form to be filled in by each subject included sex, age, handedness, clinical specialty, years of clinical experience, years of microsurgical experience, surgical volume for bypass surgery, and surgical volume for the past year. The experimental protocol and data disclosure policy were approved by the ethics

committee of the School of Engineering at The University of Tokyo.

The task was an end-to-end anastomosis of 0.7-mm artificial blood vessels (material: silicone; Microvascular Practice Card, Muranaka Medical Instruments Co., Ltd., Tokyo, Japan) with 3 stitches using a 10-0 surgical suture (10V43-10R, Muranaka Medical Instruments Co., Ltd.) cut to 30 mm. Each stitch was secured with 3 knots. The artificial vessels were fixed on the desk with a rotational angle of 30 degrees.

To validate this system, the quantitative data needed to be correlated with a subjective evaluation by experts. Thus, we asked 3 blinded expert surgeons (who is doing the task on the video) (A.M., T.K., R.T.) to assess each participant's skill by reviewing videos recorded during the anastomosis and photos of the anastomosed vessels. We revised the conventional assessment score (formerly called the Medical Assessment Score) defined in the initial article (3) and renamed it the visual assessment score (VAS). To determine the VAS, 10 possible points were given for each of the 3 tasks of the anastomosis (needle placement, suture handling, and knot-tying) performed by each participant, and -3 to 0 penalty points were included for the appearance of the anastomosed artificial blood vessels. In other words, each evaluator could assign a maximum of 30 points to each participant. The scores for all participants given by each evaluator were standardized to compensate for any individual differences among the evaluators. This standardization transformed a variable into a rescaled variable with a mean of zero and a variance of one. Thereafter, the standardized scores from the three evaluators were

averaged and referred to as the VAS. In this analysis, surgeons with a positive VAS were considered skilled and those with a negative VAS were considered unskilled.

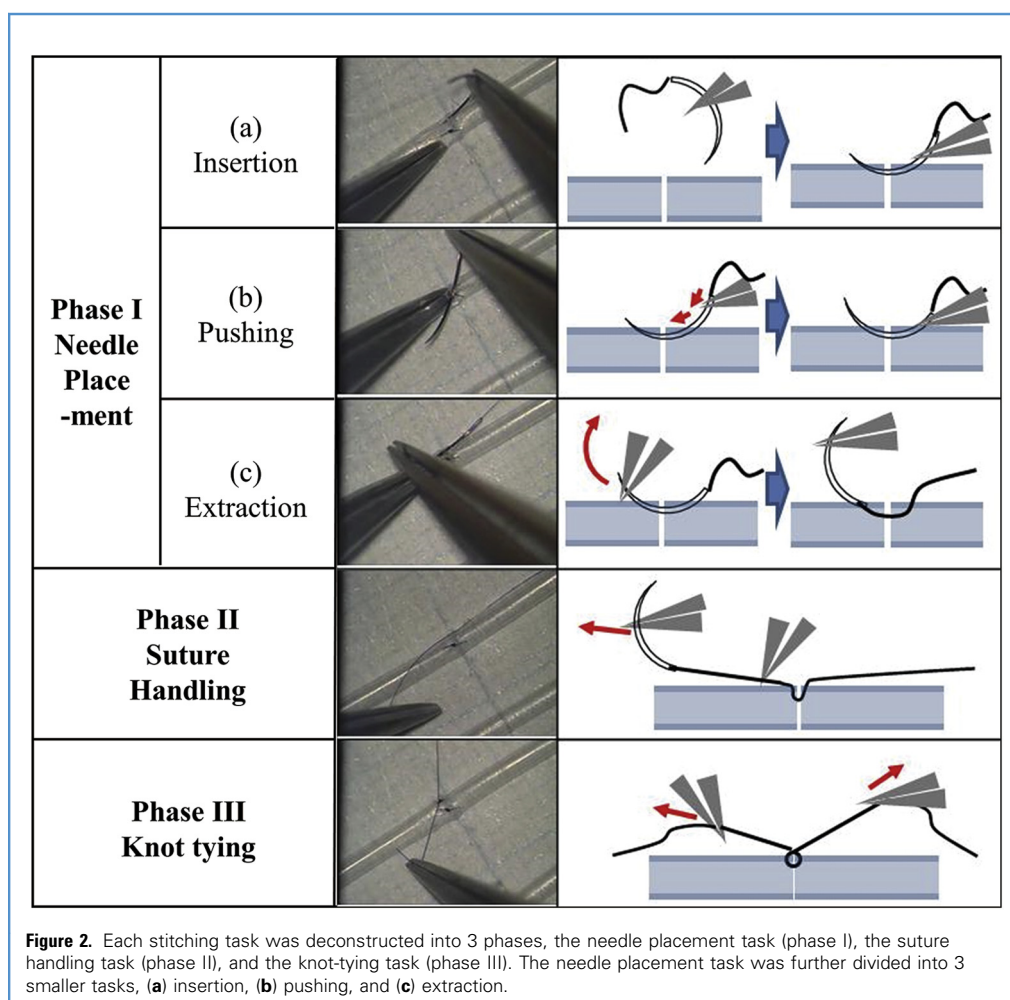
According to the classification by McBeth et al. (9) in our experiments, each stitching task was deconstructed into 3 smaller tasks: needle placement (phase I), suture handling (phase II), and knot tying (phase III), as shown in Figure 2. The needle placement task was further divided into 3 smaller tasks: insertion, pushing, and extraction. These 3 tasks of needle placement are unique in microsurgery because very precise force control is crucial to prevent damage to small blood vessels. To deconstruct the tasks, all videos were carefully reviewed by a researcher in the Engineering Department (K.H., Y.M., Y.M.B.), and the start- and end-frames of each task were tagged and mapped on sensory data. The data for each task were then compared between unskilled and skilled surgeons by using the Wilcoxon rank-sum test with JMP statistical software (SAS Institute, Inc., Cary, North Carolina, USA), and a P-value < 0.05 was deemed statistically significant.

## RESULTS

Overall, 23 neurosurgeons participated in the experiment. All were male and right-handed, and their ages ranged from 25 to 53 years (mean  $\pm$  SD,  $37.3 \pm 10.4$ ). Their clinical experience ranged widely and is summarized in Table 1. The experiment took 15–30 minutes total for each subject, including the time needed to explain the research background and experimental method, and for registration, sensor calibration, and measurement. In total, 69 stitches made by the 23 surgeons were measured. The data for 42 stitches were valid for analysis. The data for the other 27 stitches were invalidated because the artificial blood vessels were torn by the needle or suture and the stitching task was incomplete. One unskilled surgeon could not complete the anastomosis successfully and no reliable engineered data were obtained.

### Visual Assessment Scores

The reliability of the VAS among the 3 blinded reviewers was high, and the Cronbach coefficient  $\alpha$  was 0.85. Table 2 shows



**Table 1.** Experience of the 23 Surgeons

Category	Experience	Average (SD)
Clinical experience (chronological years)	1 ~ 28 years	11.3 (10.0) years
Microsurgery experience (years)	0 ~ 28 years	8.5 (9.4) years
Bypass surgery volume	0 ~ 300 cases	48.6 (82.0) cases
Surgical volume in the past year	0 ~ 300 cases	74.4 (90.8) cases
SD, standard deviation.		

the Pearson product-moment correlation coefficients for comparisons of the registered subject properties and the VAS. The correlation coefficients are relatively high for the volume of bypass surgery and the surgical volume for the past year. This finding suggests that the subjects' clinical experience in chronological years did not result in high VAS scores. In contrast, surgeons who recently conducted many bypass operations obtained a high VAS, demonstrating their refined skills.

**Figure 3** shows photos of stitches done by the surgeons with the highest and lowest VAS, including tool paths (front views) and needle-gripping forces for phase I. The surgeons with a high VAS demonstrated flawless motion with intermittent force and the use of the left hand during needle placement. Results were analyzed by comparing stitches made by skilled ( $n = 19$ ) and unskilled surgeons ( $n = 23$ ). **Table 3** shows the data for individual surgeons sorted by the VAS. Data from one unskilled surgeon who could not complete the task was omitted from the analysis.

### Task Completion Time

**Figure 4** shows the task completion time for each stitch and the times for each phase. The skilled surgeons made a stitch significantly faster than the unskilled surgeons ( $P < 0.01$ ). The times for needle placement (phase I) and knot tying (phase III) were also significantly shorter ( $P < 0.05$ ). There was no statistical difference between the skilled and unskilled surgeons in completing phase II (suture handling). Data from the videos showed that some unskilled surgeons, in particular junior surgeons, did not know the proper needle-holding posture or adequate knot-tying methods.

**Table 2.** Correlation of Subject Properties and VAS

Registered Subject Properties vs. VAS	Correlation Coefficient	P-Value
Clinical experience vs. VAS	0.17	0.44
Experience in microsurgery vs. VAS	0.17	0.45
Surgical volume — bypass surgery vs. VAS	0.37	0.08
Surgical volume — last year vs. VAS	0.44	0.04
VAS, visual assessment score.		

### Tool Path

**Figure 5** shows the tool paths of the right and left hands for each stitch. Compared with unskilled surgeons, the skilled surgeons performed a stitch with a significantly shorter tool path for both hands ( $P < 0.01$ ).

### Needle-Gripping Force

**Figure 6** shows the maximum needle-gripping force, which was obtained by checking which hand was used in each phase. The force data for Phase I(b), needle pushing, was valid when the needle pushing phase was clearly separated from Phase I(a), needle insertion. The data from 13 stitches in Phase I(a) and (b) could not be separated, while the data from 16 stitches made by unskilled surgeons and 13 stitches by skilled surgeons were valid for analyzing the force during Phase I(b), needle pushing. The results showed that the skilled surgeons applied significantly less force during Phase I(c), needle extraction ( $P < 0.05$ ). In other phases (I(a), I(b), II, and III), there was no statistically significant difference in the maximum gripping force during stitches between unskilled and skilled surgeons. Although not statistically significant, the force applied by skilled surgeons was somewhat less in all phases.

## DISCUSSION

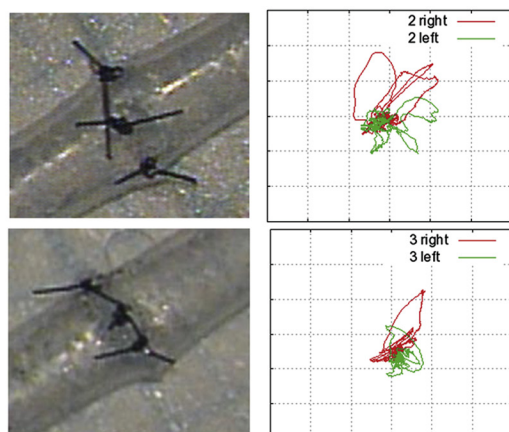
The eventual goal of studies that assess surgical skills and surgical simulators is to improve care for patients undergoing surgery by improving the surgical skills of the trainees. But as noted by Kirkman et al. (6), studies of surgical simulation and its effect on surgical training are generally poor in quality because they lack evidence-based methodology. In addition, there is no clear-cut objective method that can be used to assess surgical skills, especially in the field of microsurgery. In this study, we aimed to develop an objective skill-assessment system for micro-neurosurgery.

Some recent studies have described the quantitative assessment of surgical motion using sensors. For example, Grober et al. (2) found that tracking hand motion through miniaturized electromagnetic sensors attached on the dorsal side of the hand is a valid measure to assess skill. This method, however, is not adequate for procedures such as microvascular anastomosis in neurosurgery because microsurgeons move the fingers instead of the hands. Meanwhile, McBeth et al. (9) measured the trajectory, excursion, and velocity of the tool tip using an optical motion tracking system and evaluated a microvascular anastomosis by one experienced surgeon. Lin et al. (7) placed inertial measurement units on tweezers to evaluate the tool tip acceleration and angular velocity, but only 1 of the 14 subjects was a medical doctor, and the task was not based on actual surgical tasks.

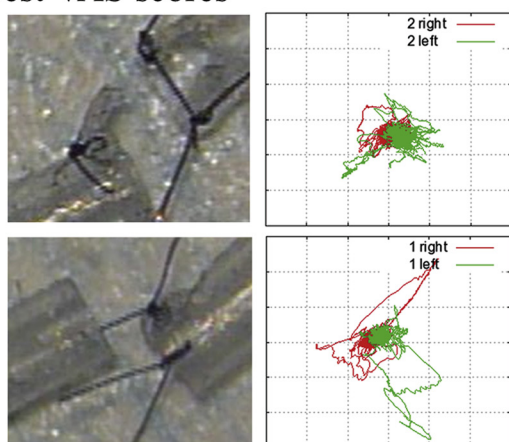
Force is an important metric in assessing surgical skill. Trejos et al. (11) implemented a force-sensing capability in a laparoscopic forceps, whereas Horeman et al. (4) incorporated a force sensor into a platform on which an artificial skin was fixed for suturing practice. Furthermore, a microsurgical simulator called NeuroTouch (National Research Council Canada, <http://www.neurotouch.ca/eng/partners.html>) was created for microneurosurgical training (1). It is an excellent surgical



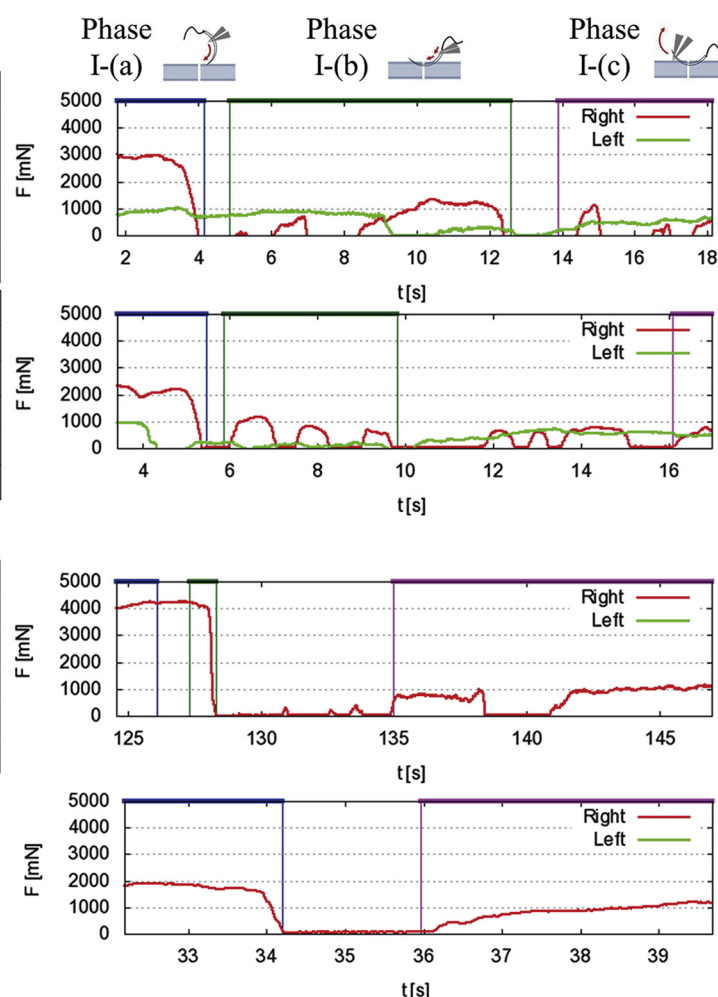
## Highest VAS scores



## Lowest VAS scores



**Figure 3.** Examples of the anastomosed artificial blood vessels, tool paths (front views) (left side), and needle-gripping forces in phase I (right side).



Comparison of procedures between surgeons with the highest (upper half) and lowest (lower half) visual assessment score (VAS).

training system but can be applied only to pre-set surgical scenarios and procedures included in the program; it cannot be applied to real surgical objects or used in daily practice for simple microprocedures. In addition, the system does not measure the tool's gripping force, whose precise control is often important for the manipulation of a needle and handling of fragile tissues.

These aforementioned devices are promising, but the parameters representing high microsurgical skills such as microvascular anastomosis are yet to be identified. In addition, experiments that include both novice and expert surgeons need to be conducted to quantify the skills. Therefore, an integrated measurement system needs to be developed to collect data related to the skills, and

experiments involving many surgeons with a wide range of clinical experience must be conducted.

We have developed and studied a new system to assess microsurgical skill. This system incorporates infrared optical motion tracking markers, an IMU, and strain gauges mounted on tweezers to record instrument manipulation, including measuring motion and sensing force. The results clearly demonstrate the potential contribution of this system in assessing microsurgical skill.

One pitfall of our experiment is that data from many of the stitches analyzed were invalidated because the artificial blood vessels used in the experiments were very fragile and easily torn, thus rendering the stitching task incomplete. Although we didn't

**Table 3.** Results of Experiments Sorted by VAS

Group	VAS	Time(s)				Path, mm		Force (N)				
		Total	Phase I	Phase II	Phase III	Right	Left	Phase I(a)	Phase I(b)	Phase I(c)	Phase II	Phase III
Unskilled	−1.99	389	188	47	154	3663	3731	4.2	4.2	1.2	2.1	4.8
	−1.56	217	51	26	140	2423	2355	1.9		1.2	2.3	3.8
	−0.77	129	42	22	65	1626	1828	1.3	0.6	0.6	1.3	4.1
	−0.64	112	38	27	48	1167	1007	2.5	0.8	0.3	1.0	4.4
	−0.62	101	63	22	17	1370	824	2.3	2.3	1.0	4.2	3.7
	−0.6	208	61	3	144	1814	1717	4.0	1.0	0.6	1.6	4.2
	−0.41	89	28	10	51	1584	1196	3.8	2.3	1.4	2.9	4.6
	−0.38	118	32	6	79	2278	1781	2.3	1.1	1.7	3.0	7.8
	−0.3	144	32	17	95	1311	1261	1.7	1.0	0.7	1.1	1.8
	−0.06	83	43	12	28	836	663	2.1	0.7	1.6	1.5	2.4
	−0.04	94	51	6	37	1039	941	2.5	1.4	1.3	1.8	7.3
	−0.02	74	33	11	30	774	627	1.3	0.8	0.6	1.5	4.3
Skilled	0.05	89	38	16	35	863	614	1.9		1.2	1.9	5.0
	0.29	143	50	16	77	1345	1122	1.0	0.7	0.6	0.7	2.1
	0.59	58	34	12	12	452	495	1.9	0.6	0.3	0.8	2.1
	0.61	62	21	7	34	596	490	2.7		0.8	1.8	2.9
	0.62	79	31	14	33	711	635	1.6	0.6	0.5	1.7	5.3
	0.89	63	37	14	12	628	467	0.9	0.3	0.6	1.6	2.3
	0.95	51	17	7	27	566	525	2.0		0.7	2.5	5.6
	1.08	88	34	14	39	801	738	3.4	2.1	0.6	2.6	5.6
	1.12	56	22	9	26	490	494	2.3	1.2	0.8	1.1	3.4
	1.69	70	25	24	21	751	670	3.0	1.3	1.1	7.2	7.1

VAS, visual assessment score.

The data for 1–3 stitches were averaged.

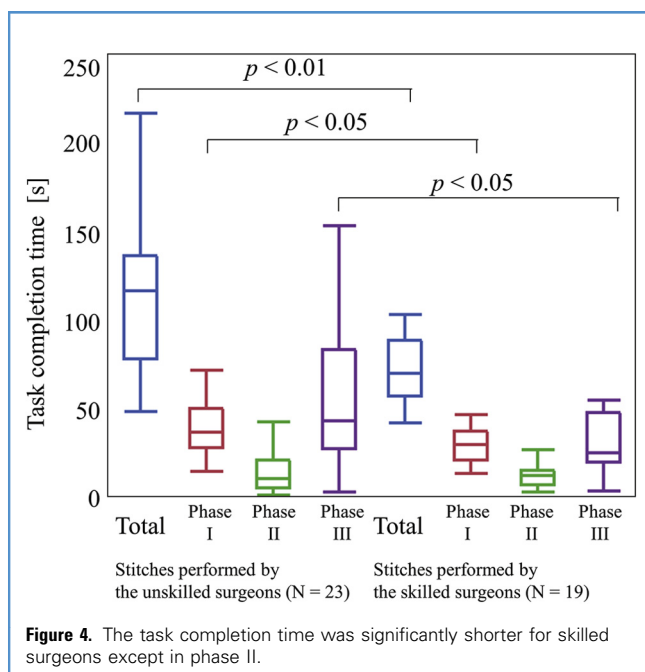
notice this problem when designing the experiment, the adequate choice of materials needs to be investigated.

Results from the visual assessment scores suggest that, when evaluating microsurgical skills, the volume of bypass surgery and the surgical volume for the past year are more important factors than the surgeon's clinical experience in years. In general, surgeons with a long duration of clinical experience are considered skilled, but microsurgical skills require good physical ability and continuous training. Thus, the length of experience in years does not necessarily correlate with good microsurgical skills. Results from task completion time and tool path showed that the tasks performed by skilled surgeons were efficient. As data from the videos show, knowledge of proper needle-holding posture and good knot-tying methods is crucial, especially for junior surgeons.

The most interesting data came from the results of the maximum needle-gripping force. McBeth et al. (9) proposed surgical skill assessments on the basis of deconstructed tasks,

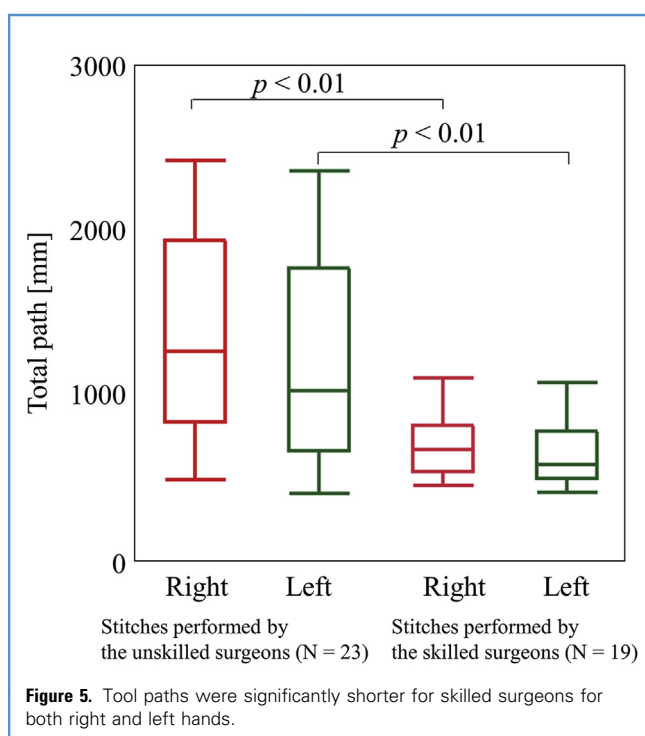
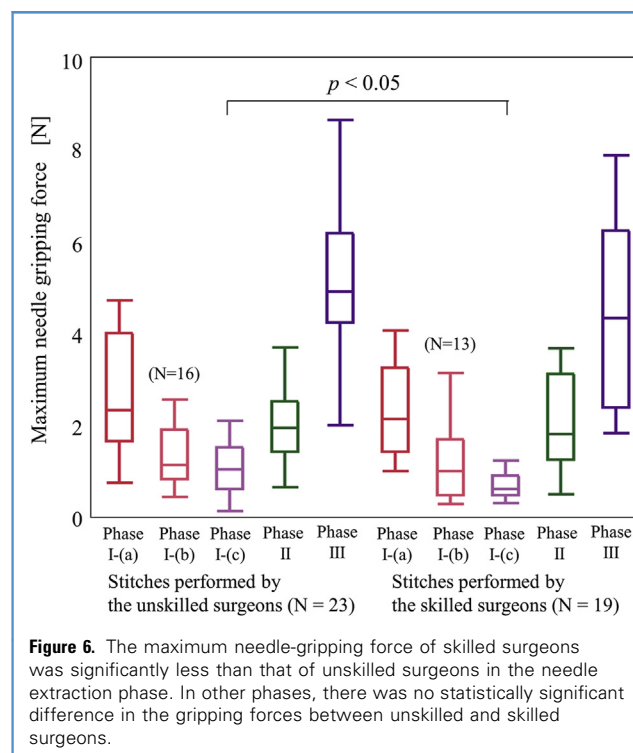
namely, needle placement and knot tying. Their results showed that deconstructing the surgical task can provide deeper insight. In the current study, we assessed the gripping force considering the phases by this classification. The skilled surgeons decreased their needle-gripping force once the needle was inserted into the vessel and very gently extracted the needle. Although we have not quantified these data, some experts used intermittent increases in force while pushing and extracting the needle to prevent damage to the blood vessels, and frequent use of the left hand also was evident. We can likely assume that skilled surgeons probably know that these motions are important for excellent microvascular anastomosis, and our assessment system successfully documented such skills.

The data from our assessment system showed the actual good techniques of skilled surgeons in numeric terms. Quantifying and visualizing these skills can help observers rate microsurgical skills objectively and help surgeons understand the key features of high microsurgical skill.



### Limitations

We have not evaluated data from a second trial to determine whether unskilled surgeons improved after they were informed of inferior techniques. Further study is mandatory to evaluate



whether such a skill-assessment system can improve training efficiency.

With regard to surgical education, knowledge and dynamic judgments based on experience and daily training are essential. In the future, with lesser surgical experience as the result of training-hour rules and the development of multiple alternative modalities that eliminate surgery, we will require high-end simulators that can assess knowledge and skills, including judgment, for various scenarios such as conditions in which control is difficult. Medical-engineering concepts and technology should greatly support developing such systems.

### CONCLUSIONS

We developed a microsurgical skill assessment system capable of measuring parameters related to instrument handling. The results show that skilled surgeons performed an anastomosis in a shorter time, with a shorter tool path, and with less force during needle extraction. A quantitative and detailed analysis of microsurgical tasks can help surgeons better understand the key features of high microsurgical skill. The collected data will be further analyzed to help develop future training systems.

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